

THE ACCRETIONARY COOLING MODEL-AVERIFICATION. A. Ghosh and H. Y. McSween Jr., Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996

Accretionary cooling is the decrease in temperature of the asteroid due to the incorporation of cold material during accretion. Accretionary cooling can explain the existence of melted (4 Vesta) and unmelted (1 Ceres) asteroids at similar heliocentric distance [1] - previously argued to be a major problem against ^{26}Al heating [2]. The finite element code used in [1] takes into account heat loss by diffusion, collisional energy and radiogenic heat in each control volume of the asteroid. However, the process is counterintuitive; hence, a more comprehensive calculation is required. Here, a more detailed explanation of the concept is presented based on observations from a finite element simulation as well as simpler spreadsheet calculations.

Methodology: A finite element code has been developed to study the thermal history of asteroidal bodies. The generic heat transfer equation is solved, and a radiation boundary condition is implemented on the surface of the asteroid. The following heat sources are used in modeling: heat from the decay of ^{26}Al and ^{60}Fe and collisional energy. In addition, spreadsheet calculations are performed to test broad concepts of energy balance in the asteroid.

Results: 1) The temperature of mass accreting to the asteroid is almost equal to the background temperature. The ratio (x) of the heat produced in the asteroidal body by radioactive decay to the heat lost from the surface by radiation is given by the following expression:

$$x = R P_{\text{rad}} / [3 \epsilon (T_{\text{ast}}^4 - T_{\text{neb}}^4)],$$

where, R = radius of the asteroid, P_{rad} = heat produced per unit time per unit volume of the asteroid, ϵ = emissivity, k = Stefan Boltzmann constant, T_{ast} = temperature of the asteroid, T_{neb} = temperature of the surrounding nebula.

For bodies of radius < 10 km, a nebular temperature of 292 K and $T_{\text{ast}} = 293$ K, $x < 1$. In other words, a planetesimal < 10 km in

radius, heated by decay of ^{26}Al and ^{60}Fe , is not capable of sustaining a temperature rise of 1 K. This means that a swarm of bodies of radius < 10 km that accrete to an asteroid can be assumed to be at the ambient temperature. On the other hand, a > 10 km target asteroid will have a lower surface area to volume ratio and will be capable of sustaining a temperature increase. Thus, the target asteroid will have a higher temperature than the accreting mass.

It is not possible for the accreting mass to be transported from a hotter portion of the nebula if theories of planetary accretion [3] by the spontaneous sweep-up of matter are to be believed.

2) If a Vesta-sized body is heated solely by collisional energy and if no heat is allowed to escape (by radiation), the maximum temperature rise possible in the whole asteroid is ~ 30 K (Fig. 1). This is in agreement with the conclusions of [4].

3) Considerable heat is produced due to ^{26}Al decay in the asteroid, but energy is expended to raise the temperature of the newly accreted cold material. At the onset of accretion, heat from radioactive decay is sufficient to compensate for the cold material accreted, and causes an overall increase in temperature. In this stage, the temperature of the asteroid increases from the ambient temperature to 500 - 700 K. But as accretion proceeds, the potency of ^{26}Al is reduced and the amount of cold material being accreted increases (the rate of accretion of mass with time is proportional to the square of the asteroid radius [3]). At this stage, heat from ^{26}Al decay can no longer neutralize the effect of accreting cold material; this causes the temperature of the asteroid to decrease to 300 - 400 K (Fig. 1). This cooling of the asteroid from an initial phase of high temperature (500 - 700 K) to a later stage of lower temperature (300 - 400 K) is referred to as accretionary cooling.

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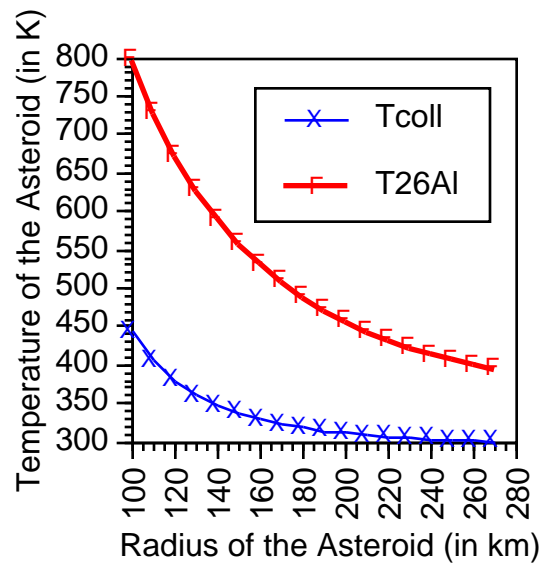


Fig 1: The results of spreadsheet calculations are shown in the above graph. The lower line (T_{coll}) in the graph traces a situation where collisional energy is the sole heat source. The upper line (T_{26Al}) assumes both ²⁶Al heating and collisional energy to be heat sources. In both the cases, the asteroid does not lose heat by radiation. The temperature of the 100 km asteroid falls from an initial temperature of 500 K to 331 K and 393 K, in the first and second case respectively, as mass increments are added causing a 10 km increase in the radius of the asteroid in each step.

References: [1] Ghosh A. and McSween H.Y. Jr. (1996) *Meteoritics* 31, A40. [2] Herbert F., et al. (1991) *The Sun in Time*, 710. [3] Wetherill G.W. (1990) *Annu. Rev. of Earth Planet. Sci.* 18, 205. [4] Melosh H. J. (1991) *Origin of the Earth*. 69-84.